2 Global emissions trends

Lead authors:

William F. Lamb (Mercator Research Institute on Global Commons and Climate Change and Priestley International Centre for Climate, School of Earth and Environment, University of Leeds, United Kingdom), Giacomo Grassi (European Commission, Joint Research Centre [JRC], Italy)

Contributing authors:

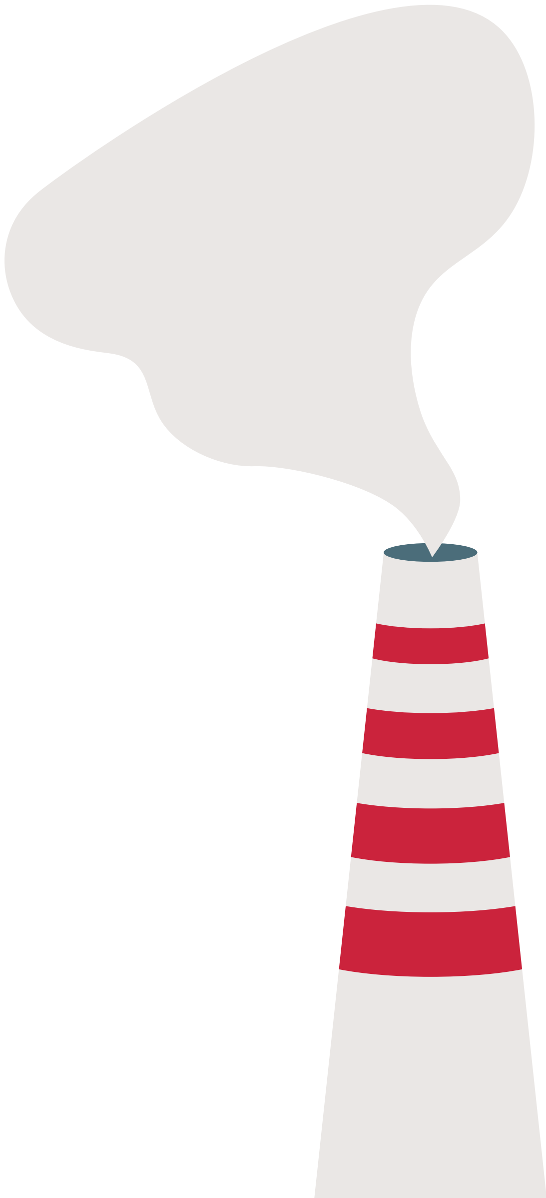
Lucas Chancel (World Inequality Lab, Paris School of Economics, France), Monica Crippa (European Commission, JRC, Italy), Diego Guizzardi (European Commission, JRC, Italy), Marilena Muntean (European Commission, JRC, Italy), Jos Olivier (PBL Netherlands Environmental Assessment Agency, the Netherlands), Glen Peters (CICERO Center for International Climate Research, Norway), Julia Pongratz (Ludwig-Maximilians University Munich, Max Planck Institute for Meteorology, Germany)

2.1 Introduction

This chapter assesses trends in greenhouse gas (GHG) emissions up to and including 2021. It analyses global emissions by gas, country, household and sector, providing the current and historical context for subsequent chapters on country pledges and mitigation pathways.

There are both short- and long-term influences on GHG emissions. In the short term, abrupt geopolitical and economic events such as the COVID-19 pandemic and the war in Ukraine can lead to significant but temporary changes in annual emissions. In the long term, structural shifts in technologies, production and investment decisions, as well as economic and climate policies, play an important role. One aim of this chapter is to provide both short- and long-term perspectives on trends in global GHG emissions.

Another focal area of the chapter is land use, land-use change and forestry emissions (LULUCF). The LULUCF sector is complex in terms of definitions, concepts and quantification, due to the scientific challenge of separating human from natural influences on GHG fluxes, and the fact that it is both a source and sink of CO_2. This year, the Emissions Gap Report has adopted a new approach for LULUCF emissions, as described in box 2.1.



Box 2.1 Methodological update to ensure consistency between global and national LULUCF emission estimates

Recent literature has highlighted significant differences in anthropogenic LULUCF estimates between the approach undertaken by countries in their reporting to the United Nations Framework Convention on Climate Change (UNFCCC) ('national inventory approach') and the global modelling approach ('bookkeeping approach') pioneered in the scientific community and used in the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (Grassi *et al.* 2021; Grassi, Schwingshackl *et al.* 2022). Both approaches are applicable in their specific contexts, but are not directly comparable as they use different system boundaries. The main conceptual difference is that bookkeeping models consider as anthropogenic only the fluxes that are due to direct human-induced effects, such as land-use change, shifting cultivation, harvest and regrowth. By contrast, national inventories generally consider as anthropogenic all the fluxes occurring on a larger area of managed forest than that used by models, and include most indirect human-induced effects on this area that models consider natural (i.e. the natural response to human-induced environmental changes such as increased CO_2 atmospheric concentration and nitrogen deposition, which enhance tree growth). Other reasons for the difference can arise from the limited representation of land management in global models and varying levels of accuracy and completeness of estimated LULUCF fluxes in national inventories. These differences hamper comparability between national inventories and bookkeeping models for the historical period, and between nationally determined contributions (NDCs) (based on the national inventory approach) and integrated assessment models (based on the bookkeeping approach) for projections.

To reflect and address this, the methodological approach to LULUCF emissions data is updated: when depicting country emissions trends, national inventory data is used. In this chapter this applies to historical emissions (based on Grassi, Conchedda *et al.* 2022 and gap-filled when necessary), and in chapter 3 it applies to country NDC emissions. When reporting global total GHG emissions, data from global models, i.e. the bookkeeping approach, is used. This chapter uses bookkeeping models that only cover LULUCF emissions (based on Friedlingstein *et al.* 2022), while chapter 4 uses integrated assessment models. This approach ensures that country estimates are consistent with those reported by countries themselves to the UNFCCC, and that global estimates are consistent with the carbon cycle, scenarios and climate science literature used in the IPCC Assessment Reports.

In addition, a harmonization procedure has been implemented in chapter 4 to ensure comparability between globally aggregated NDC estimates and integrated assessment model emission pathways consistent with different warming levels. The harmonization procedure adjusts global NDC scenarios to the outputs from integrated assessment models for the historical period.

For further details, please see appendix A, which is available online.

All GHG emission figures in this report are expressed using global warming potential over 100 years (GWP100) from the IPCC *Sixth Assessment Report* (Forster *et al.* 2021). In line with previous reports, non-LULUCF emissions in this chapter are based on a single consistent global source, the Emissions Database for Global Atmospheric Research (EDGAR), which is available up to 2021 (Crippa *et al.* 2022).[1] LULUCF emissions, based on both Grassi, Conchedda *et al.* (2022) and Friedlingstein *et al.* (2022), are currently only available up to 2020, limiting our analysis of total global GHG emissions to 2020. Nonetheless, an initial estimate of total global GHG emissions in 2021 excluding LULUCF is provided.

It should be noted that the emissions estimates presented differ from the Emissions Gap Report 2021 (United Nations Environment Programme [UNEP] 2021) due to the revision of the LULUCF data and the switch to GWP100 values from the *Sixth Assessment Report*. If total GHG estimates excluding LULUCF are recalculated based on the GWP100 from the IPCC Fourth Assessment Report, they show strong agreement with previous reports. Further information on the data used, estimations of growth rates and uncertainties is provided in appendix A, available online.

1 EDGAR includes all anthropogenic GHG emissions sources defined in the IPCC guidance and reflected in UNFCCC national inventories. Some additional sources with relevant warming impacts, such as chlorofluorocarbons, hydrochlorofluorocarbons and hydrogen gas are excluded (Minx *et al.* 2021; Dhakal *et al.* 2022).

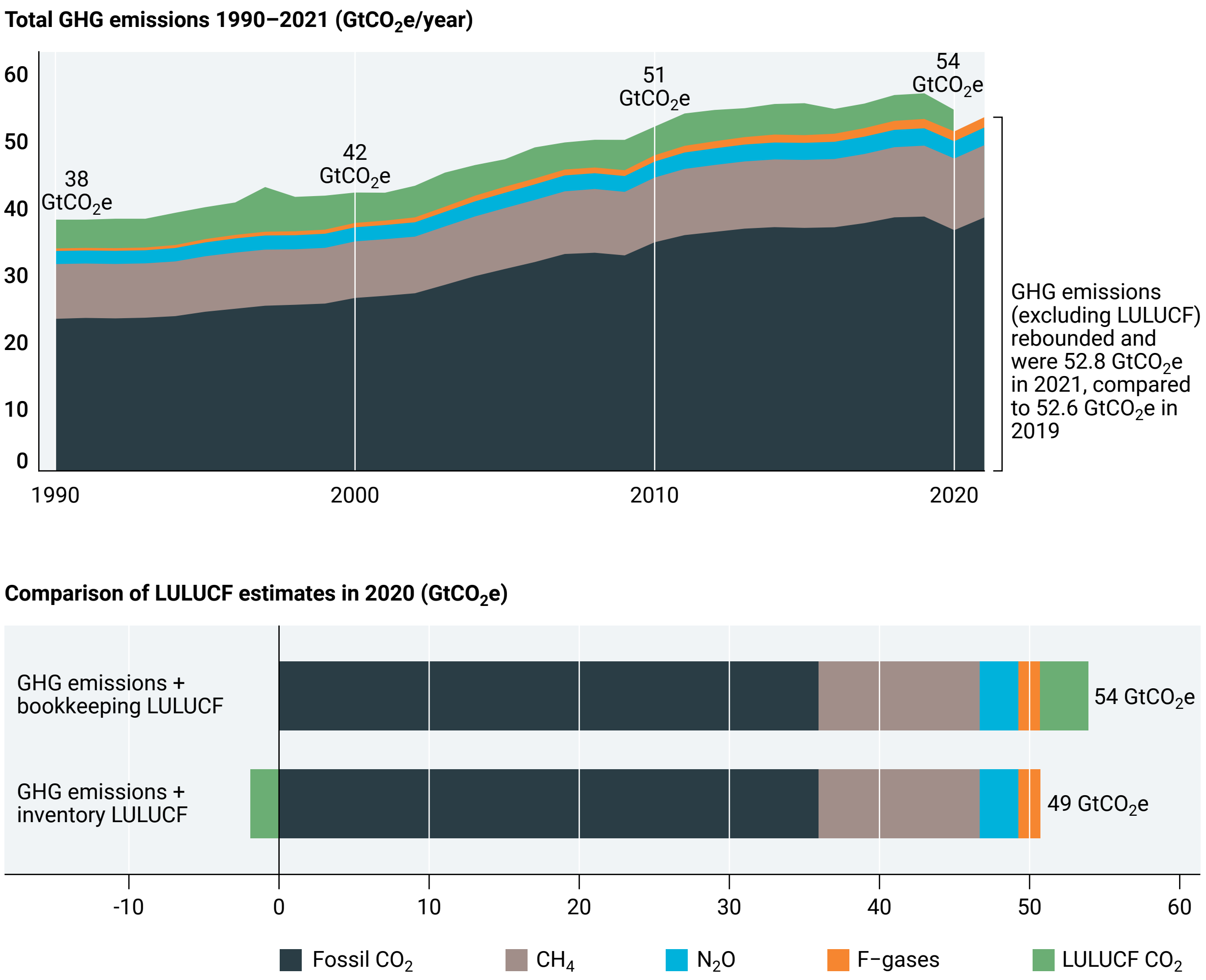
2.2 Global emissions trends

2.2.1 The rate of growth in GHG emissions has slowed in the past decade, but global GHG emissions could set a new record in 2021

While the rate of growth in GHG emissions (including LULUCF) in the past decade has slowed compared to the previous decade, average GHG emissions in the last decade were the highest on record (figure 2.1). Between 2010 and 2019, average annual growth was 1.1 per cent per year, compared to 2.6 per cent per year between 2000 and 2009. Reasons for this decadal slowdown include a global reduction in new coal capacity additions (particularly in China), the steady substitution of coal by gas in the power sectors of developed countries, the increasing pace of renewable energy deployments worldwide (Lamb, Wiedmann *et al.* 2021; Dhakal *et al.* 2022; Friedlingstein *et al.* 2022; Jackson *et al.* 2022;) and a reduction in LULUCF net emissions, although these are very uncertain (Friedlingstein *et al.* 2022). This raises the question of whether global GHG emissions are reaching a plateau, or whether slower levels of growth will continue in the coming years (see also section 2.2.3).

Total global GHG emissions averaged 54.4 gigatons of CO_2 equivalent ($GtCO_2e$) between 2010 and 2019, and reached a high in 2019 (figure 2.1, table 2.1). Estimates of LULUCF emissions for 2021 are not yet available, preventing conclusions regarding total global GHG emissions in 2021. However, the initial estimate of total global GHG emissions excluding LULUCF for 2021 exceeds comparable levels in 2019 by 0.26 $GtCO_2e$, or 0.2 per cent (table 2.1), suggesting that total global GHG emissions in 2021 will be similar to, or even surpassing, 2019 levels.

Figure 2.1 Total GHG emissions 1990–2021 and comparison of LULUCF estimates



Sources: Crippa *et al.* (2022); Friedlingstein *et al.* (2022); Grassi, Conchedda *et al.* (2022)

Note: Total emissions include CO_2 from fossil fuel and industry (fossil CO_2), CO_2 emissions from LULUCF, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases). LULUCF CO_2 emissions are depicted in the top panel up to 2020 as a net global source using the bookkeeping approach from the Global Carbon Budget (no data is available for 2021). A comparison of the bookkeeping to the national GHG inventory approach is provided in the lower panel for the year 2020.

This confirms that the global response to the COVID-19 pandemic had an unprecedented but short-lived effect on emissions (figure 2.1, table 2.1). Total global GHG emissions dropped 4.7 per cent from 2019 to 2020 – the largest single-year absolute drop in GHG emissions since 1970 when the data set starts (Dhakal *et al.* 2022). Nonetheless, daily emissions data suggests that CO_2 emissions from fossil fuel and industry (hereafter referred to as fossil CO_2 for brevity) had already rebounded by the end of 2020 (Le Quéré *et al.* 2020; Liu *et al.* 2020; Davis *et al.* 2022; Jackson *et al.* 2022).

Global atmospheric CO_2 concentrations continued to grow from 2019 to 2020, reaching an annual mean of 413 parts per million. This was slightly slower than during 2018 to 2019, but faster than the decadal average rate, despite COVID-19 restrictions (World Meteorological Organization 2022).

The long-term impacts of COVID-19 on global GHG emissions are not yet possible to discern (Kikstra *et al.* 2021; Shan *et al.* 2021). On the one hand, the global response to COVID-19 has disrupted supply chains and may have led to underlying shifts in energy supply and demand; on the other hand, economic stimulus packages appear to have favoured fossil fuels, missing an opportunity to support renewable energy and low-carbon investments (Hepburn *et al.* 2020; UNEP 2020; Bertram *et al.* 2021; Le Quéré *et al.* 2021; UNEP 2021). Emissions trends in 2022 and beyond will be further influenced by the war in Ukraine and subsequent disruptions to global energy supplies, which are driving a renewed policy focus on energy security. Early assessments project an increase in fossil fuel investments in 2022, as many countries have announced plans to expand natural gas infrastructures to shore up domestic supplies (Climate Action Tracker 2022; International Energy Agency 2022).

Table 2.1 Total emissions by source, 2019–2021

Year	$GtCO_2$	CH_4, N_2O, F-gases ($GtCO_2e$)	LULUCF ($GtCO_2$)	Total GHG emissions excluding LULUCF ($GtCO_2e$)	Total GHG emissions ($GtCO_2e$)
2021	37.9 (± 3)	15 (± 3.6)	N/A	52.8	N/A
2020	36 (±2.9)	14.8 (± 3.6)	3.2 (± 2.2)	50.8	54
2019	38 (±3)	14.6 (± 3.6)	3.8 (± 2.2)	52.6	56.4

2.2.2 COVID-19 responses mainly impacted CO_2 emissions from fossil fuels and industry, while methane and nitrous oxide remained steady, and F-gases continued to surge

Fossil CO_2 emissions declined by 5.6 per cent from 2019 to 2020, but rebounded to levels comparable to 2019 levels in 2021 (table 2.1). Methane, nitrous oxide and F-gas emissions continued to grow during and after the initial COVID-19 pandemic response. These non-CO_2 emissions sources are mainly linked to agricultural activities (methane and nitrous oxide), fossil fuel supply chains (methane), and cooling and industrial processes (F-gases). That they followed the longer-term trend of steady growth (for F-gas emissions, rapid growth) indicates that these sectors were less exposed to the energy demand reduction dynamics of the initial COVID-19 pandemic response.

At a source level, emissions from oil saw the steepest drop in 2020, followed by coal and gas (Friedlingstein *et al.* 2022). Oil is mainly used in land transport and aviation and shipping, which were most severely affected by the pandemic (Le Quéré *et al.* 2020; Liu *et al.* 2020). Emissions from oil have yet to rebound, and remained below 2019 levels in 2021 (Jackson *et al.* 2022). On the other hand, coal and gas rebounded strongly in 2021. In 2021, global coal emissions exceeded 2019 levels, mainly due to increased usage in China and India (Davis *et al.* 2022; Jackson *et al.* 2022). In some countries there has been a shift from coal to gas in recent decades; while this can reduce emissions in the short term, it has contributed the development of new gas infrastructures that have long lifetimes and cumulative emissions impacts, including via methane emissions from leakages (Alvarez *et al.* 2018).

2.2.3 LULUCF emissions remain substantial, but are deeply uncertain

Net LULUCF CO_2 emissions assessed using the bookkeeping approach (see box 2.1) experienced a small decline from 2019 to 2020, largely related to particularly large peat and tropical deforestation and degradation fires in 2019 (Friedlingstein *et al.* 2022). While the number of deforestation fires in the Amazon remained high in 2020, land-use related fire emissions in Indonesia decreased as the unusually dry conditions of 2019 ceased.

LULUCF emissions from bookkeeping models are highly uncertain in both magnitude and trend, and vary substantially by global regions (Pongratz *et al.* 2021). Average emissions between 2011 and 2020 were 4.1 ± 2.6 $GtCO_2$. The data indicates a decline in LULUCF emissions over this past decade (of 4 per cent/year). However, the literature reports a very low confidence in this trend, due to underlying data limitations (Dhakal *et al.* 2022, Friedlingstein *et al.* 2022). Whereas removals mainly take place in regions with a pretwentieth-century legacy of deforestation (i.e. Europe and North America), emissions are concentrated in tropical regions with a high present-day burden of deforestation (the Amazon basin, Southeast Asia and sub-Saharan Africa). Net emissions trends are primarily driven by deforestation, in places where the monitoring and quantification of land-use trends is challenging.

Net LULUCF emissions from national inventories remained stable between 2011 and 2020 at a decadal average of around -2 $GtCO_2$/year (appendix A, figure A.1), with temperate and boreal regions reporting net removals and tropical regions reporting close to net-zero emissions (Grassi, Conchedda *et al.* 2022). For 2011–2020, the difference in global net LULUCF CO_2 fluxes between national inventories and bookkeeping models is about 6.1 $GtCO_2$ (5.1 $GtCO_2$ for the year 2020; figure 2.1). This large difference is explained by a variety of factors, the most important being how areas of managed land and anthropogenic forest sinks are defined (Grassi *et al.* 2021; also see appendix A).

2.2.4 Sector emissions trends

Emissions can be divided among five global economic sectors: energy supply; industry; agriculture, forestry and other land-use change (AFOLU);[2] transport; and direct energy use in buildings. Since 1990, most growth in emissions has been from the energy supply, industry and transport sectors (Lamb, Wiedmann *et al.* 2021; Dhakal *et al.* 2022). In 2020, the energy supply sector contributed 20 $GtCO_2e$ (37 per cent of the total), industry was 14 $GtCO_2e$ (26 per cent), AFOLU was 9.5 $GtCO_2e$ (18 per cent), transport was 7.6 $GtCO_2e$ (14 per cent) and buildings was 3.1 $GtCO_2e$ (5.7 per cent). Reallocating the emissions associated with electricity and heat production (e.g. in the energy supply sector) to final consuming sectors increases the contribution of the industry and buildings sectors to 34 per cent and 16 per cent, respectively (Dhakal *et al.* 2022).

There are a number of particularly high-emitting subsectors that drive global emissions growth. These include electricity and heat production (14 $GtCO_2e$ in 2020, 25 per cent of the total), road transportation (5.6 $GtCO_2e$, 10 per cent), and the metals industry (3.2 $GtCO_2e$, 6 per cent). Methane emissions from enteric fermentation (i.e. livestock rearing), landfill sites, and fugitive methane emissions from oil, gas and coal supply chains, are also significant global sources with short-term warming impacts (Dhakal *et al.* 2022). As at 2021, emissions have rebounded relative to 2019 emissions across most sectors and subsectors, except for transportation, oil and gas fugitive emissions, and petroleum refining.

2.3 Emissions trends of major emitters

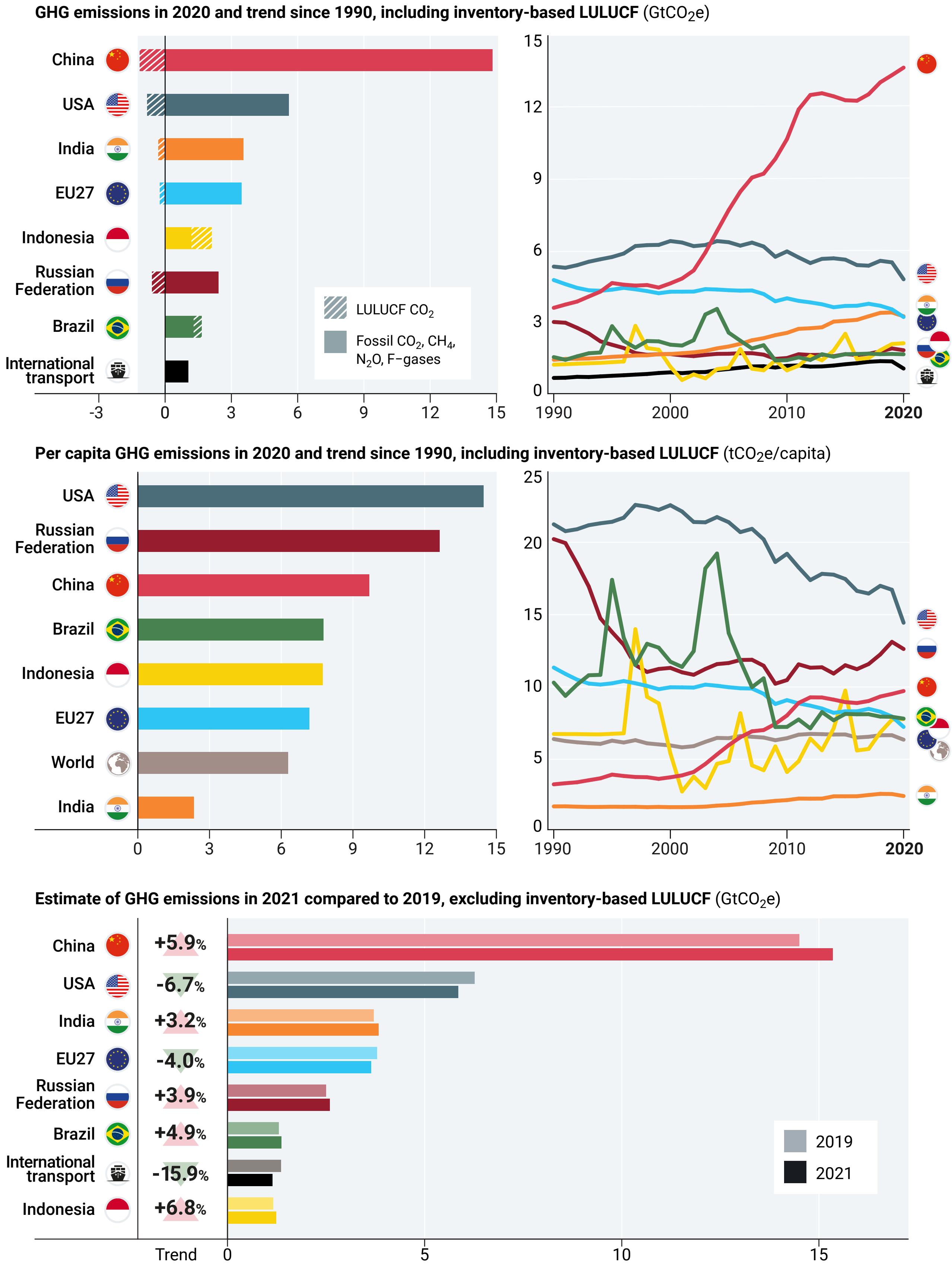
Eight major emitters – seven G20 members and international transport – contributed more than 55 per cent of total global GHG emissions in 2020: China, the United States of America, the European Union (27), India, Indonesia, Brazil, the Russian Federation, and international transport (figure 2.2). The G20 as a whole contributed 75 per cent of the total. Collectively, the emissions of the top eight fell from 32.8 $GtCO_2e$ in 2019 to 31.5 $GtCO_2e$ in 2020 (a change of -3.8 per cent).

In 2020, the LULUCF sector based on the national inventories (gap-filled when necessary) was a net sink in the emissions inventories of China, the European Union, India, the Russian Federation and the United States of America, and in 17 G20 members overall (figure 2.2). If LULUCF emissions and removals are excluded, total GHG emissions are higher by as much as 33 per cent in the Russian Federation, 17 per cent in the United States of America, 9 per cent in India, and about 8 per cent in China and the European Union. By contrast, the LULUCF sector is a net emitter in Indonesia and Brazil, accounting for 44 per cent and 22 per cent of their total emissions.

For most major emitters, including China, India, the Russian Federation, Brazil and Indonesia, GHG emissions (excluding LULUCF) rebounded in 2021, exceeding pre-pandemic 2019 levels (Crippa *et al.* 2022; Davis *et al.* 2022; Jackson *et al.* 2022). The highest increases between 2019 and 2021 were observed in Indonesia and China, at 6.8 per cent and 5.9 per cent respectively. International transport emissions in 2021 remain far below 2019 levels (-15.9 per cent) (figure 2.2).

2 AFOLU includes LULUCF CO_2 emissions, here accounted for using global bookkeeping model data, plus additional agricultural emissions from EDGAR, such as methane from livestock and rice cultivation and nitrous oxide from fertilizer application.

Figure 2.2 Total and per capita GHG emissions (including LULUCF) of major emitters in 2020 and since 1990, and estimated GHG emissions (excluding LULUCF) in 2021 compared to 2019



Sources: Crippa *et al.* (2022); Grassi, Conchedda *et al.* (2022)

Note: Where included, LULUCF emissions are based on the national inventory approach, gap-filled when necessary. Percentage values in the final panel refer to the relative emissions change between 2019 and 2021. In some countries, mainly due to deforestation, the LULUCF sector is a net source of emissions; in other countries it is a net sink of emissions, mainly due to forest regrowth and afforestation.

Per capita GHG emissions of the United States of America and the European Union have continued to decline over the past decade, while those of most other regions grew (figure 2.2). World average per capita GHG emissions (including LULUCF) were 6.3 tCO_2e in 2020. The United States of America remains far above this level at 14 tCO_2e, followed by 13 tCO_2e in the Russian Federation, 9.7 tCO_2e in China, about 7.5 tCO_2e in Brazil and Indonesia, and 7.2 tCO_2e in the European Union. India remains far below the world average at 2.4 tCO_2e. On average, least developed countries emit 2.3 tCO_2e per capita annually.

As with current per capita GHG emissions, contributions to historical cumulative CO_2 emissions (excluding LULUCF) vary greatly between countries and global regions (Gütschow *et al.* 2016; Matthews 2016). Whereas the United States of America and European Union contributed 25 per cent and 17 per cent respectively to total fossil CO_2 emissions from 1850 to 2019, China contributed 13 per cent, the Russian Federation 7 per cent, India 3 per cent, and Indonesia and Brazil 1 per cent each. Least developed countries contributed only 0.5 per cent to historical CO_2 fossil fuel and industry emissions between 1850 and 2019 (Dhakal *et al.* 2022).

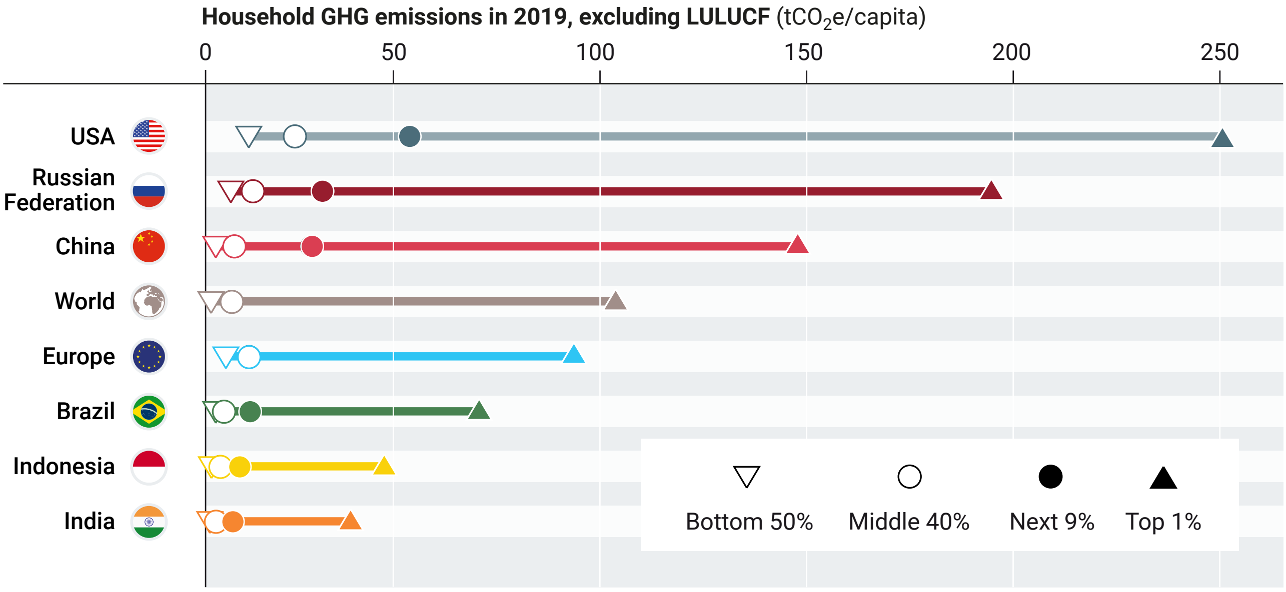
2.3.2 Consumption-based emissions are highly unequal between and within countries

When national fossil CO_2 emissions are estimated on a consumption-basis (i.e. where the supply-chain emissions are allocated to consumers) rather than on the territorial-basis considered so far, emissions tend to be higher in high-income countries such as the United States of America and European Union (by 6 per cent and 14 per cent respectively; Friedlingstein *et al.* [2020]). Conversely, they are lower in countries such as India and China (by 9 per cent and 10 per cent respectively), which are net exporters of goods. International transfers of emissions embodied in traded products peaked in 2006 and have since stabilized to be about one quarter of global CO_2 emissions, or about 6.5 $GtCO_2e$ since 2014 according to the latest assessment (Wood *et al.* 2020; Hubacek *et al.* 2021; Dhakal *et al.* 2022).

Consumption-based accounting is also relevant for AFOLU emissions, as the production of highly traded agricultural commodities such as soybeans, palm oil, grains and meat products are known to drive deforestation and create methane and nitrous oxide emissions (Pendrill *et al.* 2022). Similar to fossil CO_2 transfers, high-income countries (United States of America, European Union and Japan) tend to be net importers of agricultural products and hence have higher consumption-based AFOLU emissions. Major net exporters of such commodities and their embodied AFOLU emissions include Brazil, Indonesia, Argentina and Australia. According to Hong *et al.* (2022), in the past decade China has become the largest net importer of embodied AFOLU emissions, superseding Europe and the United States of America. Approximately 22 per cent of agricultural land worldwide is used for traded products, resulting in annual consumption-based AFOLU emissions of 4.5–5.8 $GtCO_2e$ as at 2017, excluding sinks (Hong *et al.* 2022).

Consumption-based emissions also diverge starkly at a household level, in large part due to income and wealth disparities between and within countries (Capstick, Khosla and Wang 2020). When the emissions associated with both household consumption and public and private investments are allocated to households (see appendix A), and households are ranked by GHG emissions (excluding LULUCF), the bottom 50 per cent emit on average 1.6 tCO_2e/capita and contribute 12 per cent of the global total, whereas the top 1 per cent emit on average 110 tCO_2e/capita and contribute 17 per cent of the total (Chancel 2022; Chancel *et al.* 2022). Super-emitters in the top 0.1 per cent (average 467 tCO_2e/capita) and the top 0.01 per cent (2,531 tCO_2e/capita) have seen the fastest growth in personal carbon footprints since 1990. High-emitting households are present across all major economies, and large inequalities now exist both within and between countries (figure 2.3) (Chancel *et al.* 2022).

Figure 2.3 Household consumption-based emissions, excluding LULUCF, by emissions groups



Source: Chancel *et al.* (2022)

Note: Per capita emissions include emissions from domestic consumption, public and private investments, and imports and exports of carbon embedded in trade with the rest of the world. Households are ranked according to total emissions and divided accordingly into groups (e.g. the bottom 50 per cent refers to the 50 per cent of households with the lowest emissions in that country or region).

2.3.3 Some countries have peaked emissions, but their reductions have been outweighed by emissions growth elsewhere

By 2019, 35 countries accounting for about 10 per cent of global emissions had peaked and reduced net GHG emissions, including LULUCF, for at least 10 years. These countries, which are mainly in Europe and also include the United States of America, that have started from a high base of per capita and historical cumulative emissions (Lamb, Grubb *et al.* 2021; Le Quéré *et al.* 2019). Most of them have also achieved reductions on a consumption basis.

Countries with sustained emissions reductions have tended to reduce energy system emissions via switching from coal to gas, low or negative growth in energy demand, and/or scaling up renewable energy deployments. So far, they have had limited success in reducing transport or agricultural emissions (Lamb, Grubb *et al.* 2021; Lamb, Wiedmann *et al.* 2021). However, total reductions in the annual emissions of peaking countries to date have been modest – 3.2 $GtCO_2e$ from peak years to 2018, according to one estimate (Lamb, Grubb *et al.* 2021) – and have been outweighed by global emissions growth elsewhere. As at 2019, the majority of countries had increased emissions over the past decade (74 countries, 65 per cent of global emissions), or remained stable (39 countries, 25 per cent of global emissions).